



Jet Propulsion Laboratory
California Institute of Technology

**Workshop on Technology for Direct Detection and
Characterization of Exoplanets April 11, 2018**

Exoplanet Exploration Program Technology: Decadal Survey Testbed, Segmented Coronagraph Design and Analysis, Mission Roadmap

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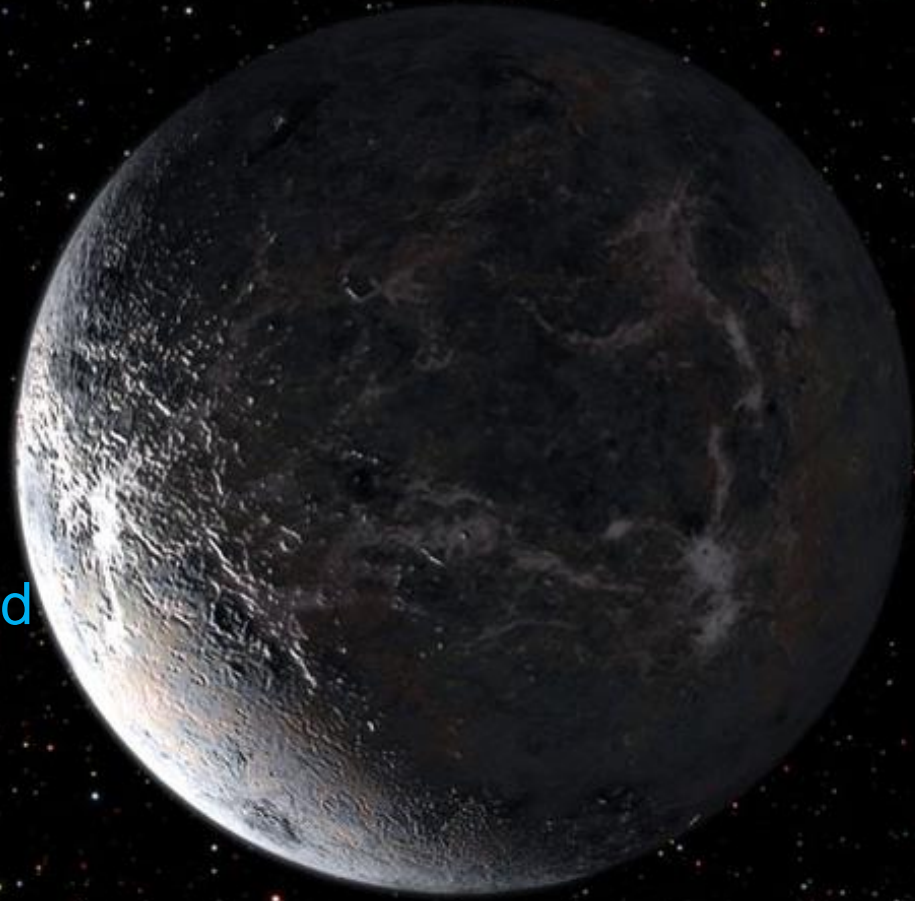
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Program Chief Technologist

NASA Exoplanet Exploration Program
Jet Propulsion Laboratory – California Institute of Technology

Pre-Decisional Information -- For
Planning and Discussion Purposes Only

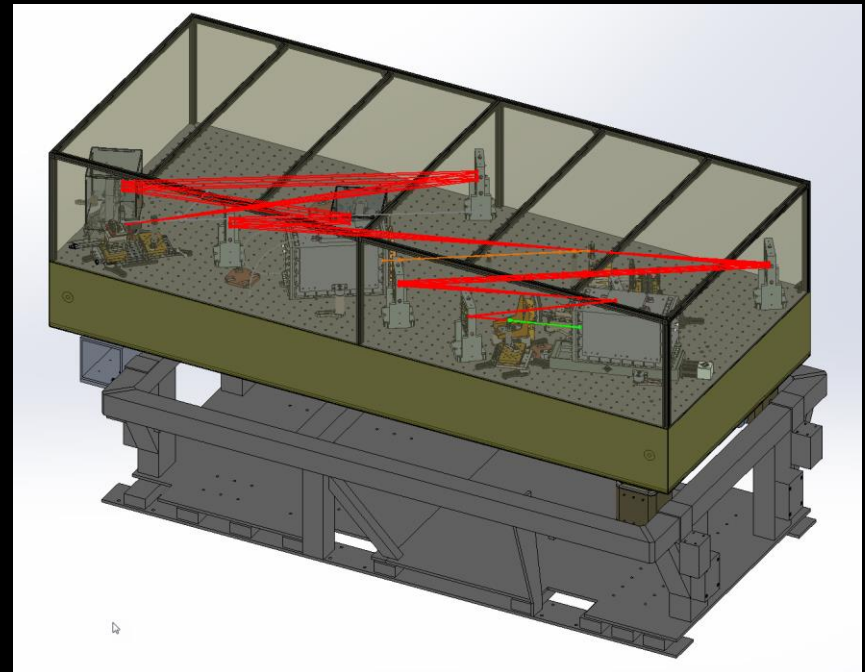
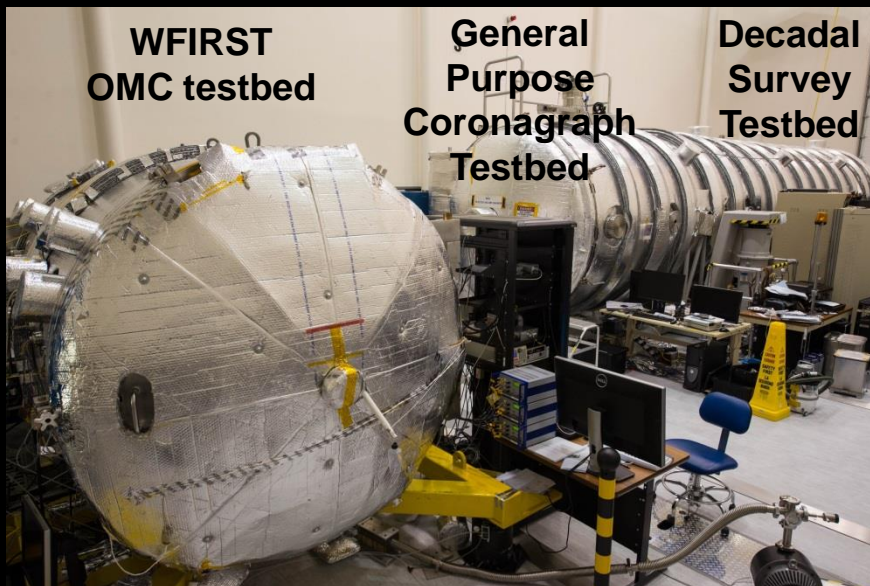
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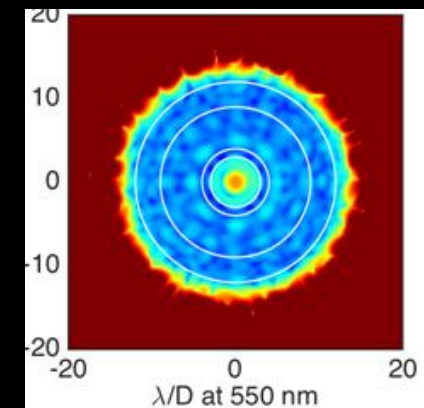
The Decadal Survey Testbed

- New coronagraph vacuum testbed facility to be commissioned in the large High Contrast Imaging Testbed 40' chamber this year
- Aim to achieve 1×10^{-10} contrast levels



Unique features of the DST

- Simple optical layout, minimize number of reflections
- Low CTE carbon composite bench
- 16-zone thermal control (including DM), MLI shrouds
- Well-characterized DM
- Jitter reduction: vacuum-compatible isolation stages
- LOWFS/C with DM mounted on a fast piezo tip-tilt stage



Decadal Survey Testbed plans

Phase I - Commissioning (clear, unobscured pupil; static demonstration)

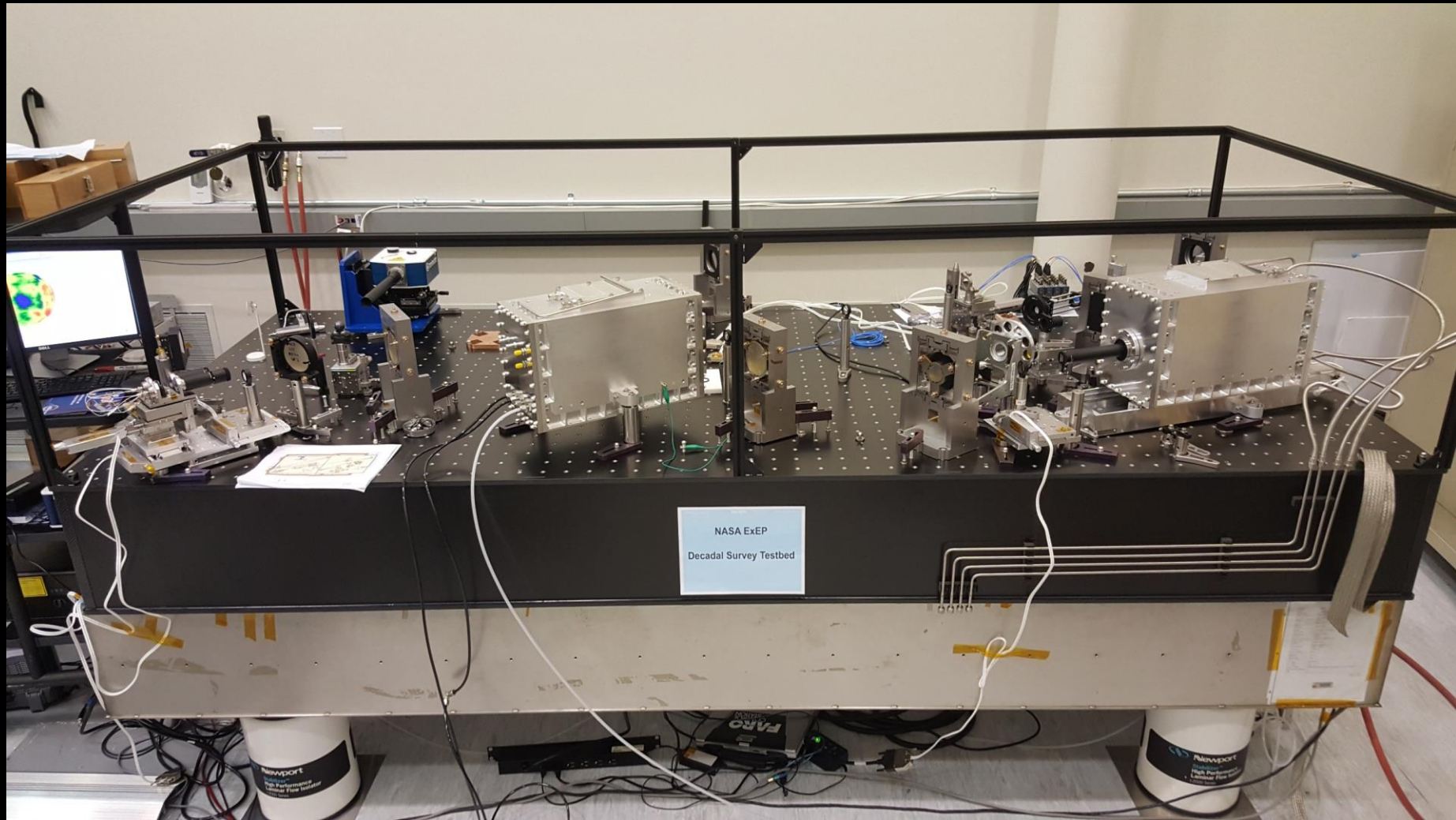
- Using a Hybrid Lyot Coronagraph architecture with an unmasked circular pupil, demonstrate a 360° annular dark hole from 3 to 9 λ/D in a 10% bandpass centered at 550 nm with mean contrast $\leq 10^{-10}$.

Phase II – Segmented Telescope (segmented, obscured pupil; static demonstration)

- Using a TBD coronagraph, add a TBD segmented pupil mask and demonstrate a 360° annular dark hole from 3 to 9 λ/D in a 10% bandpass centered at 550 nm with mean contrast $\leq 5e-10$ (TBR).

Phase III – Segmented Telescope (segmented, obscured pupil, dynamic demonstration)

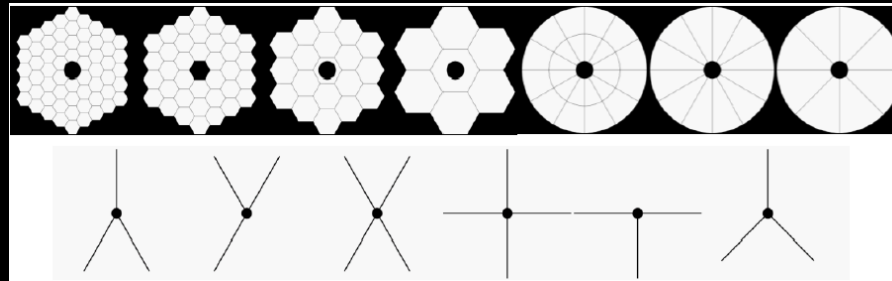
- Same as Phase II but now with a segmented telescope simulator and a disturbance source



**DST first light by next month:
DM installed this summer**

Segmented Coronagraph Design and Analysis (SCDA) study

- SCDA study is evaluating coronagraph designs for future large on-axis, segmented space telescopes



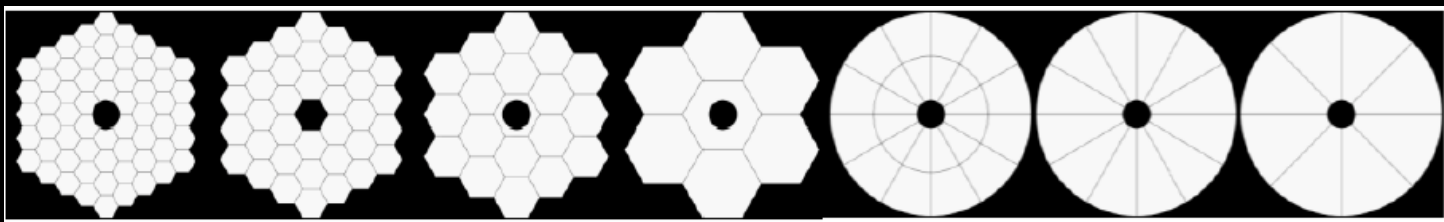
- Groups at Arizona, Ames, GSFC, STScI, JPL, Caltech, are designing coronagraphs to achieve 10^{-10} contrast -> maximize scientific yield
- Evaluate designs against a common set of metrics (such as robustness, manufacturability, does coronagraph place unrealistic demands on telescope)
- APLC design so far is the most successful architecture, though obtaining excellent throughput and IWA is still a challenge
- Apodized vortex designs for centrally obscured pupils are sensitive to stellar diameter
- PIAACMC design can be used for longer wavelengths (where stellar size is less of a problem)

Lessons from SCDA

Study of relative merits of possible segment configurations
see 2016 report by Feinberg et al. on ExEP website

Table 1 Relative challenges of designs under consideration. Green to red designates least to most challenging. No absolute scale of difficulty is implied, and the relative challenge scale of each row may be different.

	APERTURES						
Segment Shape	4 ring	3 ring	2 ring	1 ring	Keystone 24	Pie wedge 12	Pie wedge 8
Max Segm. Dimension	Hex	Hex	Hex	Hex	Keystone	Pie wedge	Pie wedge
	1.54 m	1.98 m	2.77 m	4.62 m	2.5 m x 3.14 m	5 m x 3.14 m	5 m x 4.71 m
Segments	Green	Yellow	Orange	Red	Orange	Orange	Red
Backplane	Green	Green	Orange	Red	Orange	Orange	Red
Stability	Yellow	Yellow	Yellow	Red	Yellow	Yellow	Red
Launch Configuration	Yellow	Green	Orange	Red	Orange	Orange	Red
SM Support	Green	Green	Green	Yellow	Orange	Orange	Red
Overall Ranking	Green	Yellow	Orange	Red	Orange	Orange	Red



Lessons from SCDA

Pupil obscuration from secondary mirror + supports is extremely important for determining coronagraph throughput

For example APLC designs see a large performance dropoff when secondary mirror diameter exceeds ~30% of the primary mirror diameter

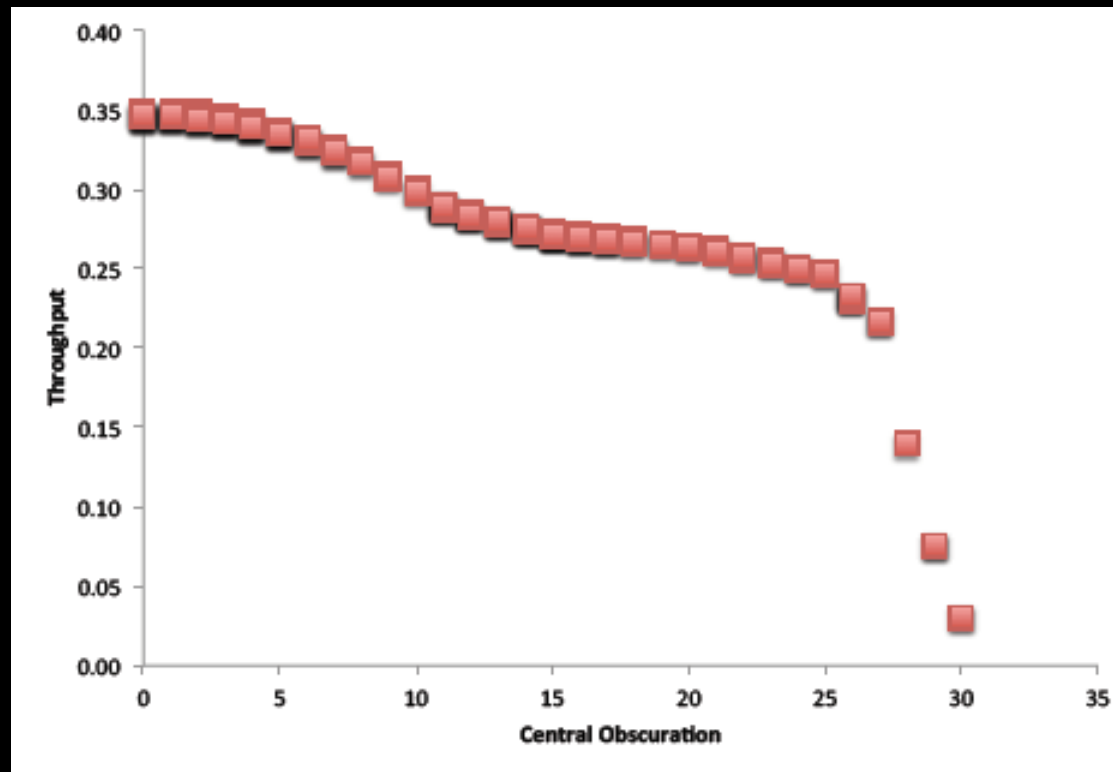
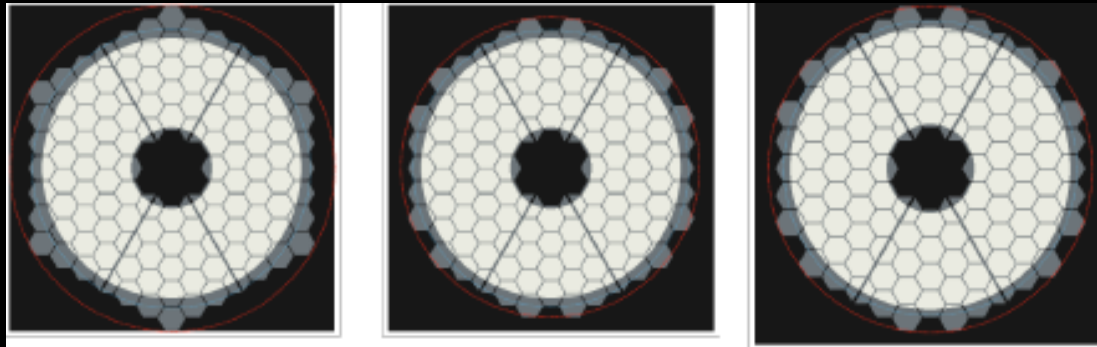


Figure courtesy of K. St Laurent

Lessons from SCDA

Inscribed diameter of primary mirror matters more than circumscribed diameter

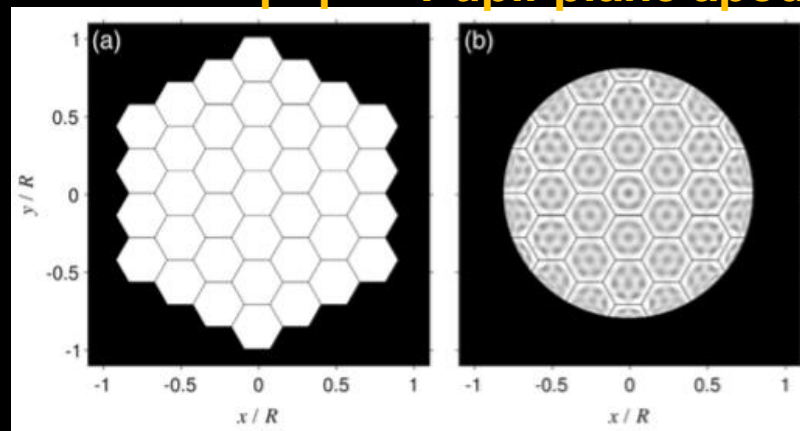
Coronagraph throughput increasing →



From Soummer et al (2017) SCDA report

If segment gaps are small, segmentation itself doesn't matter much

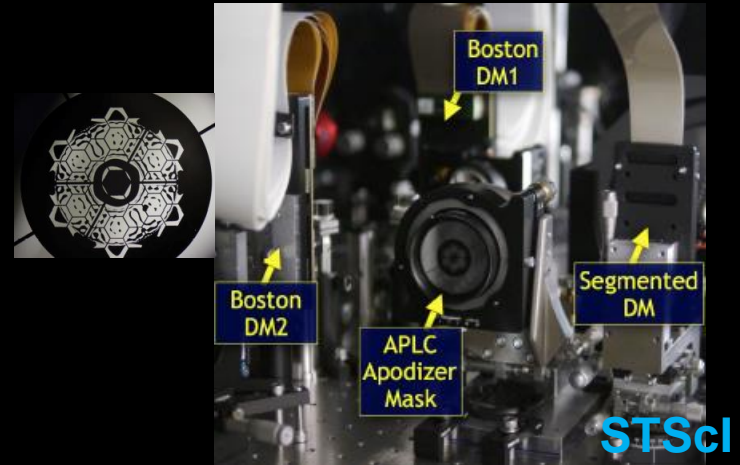
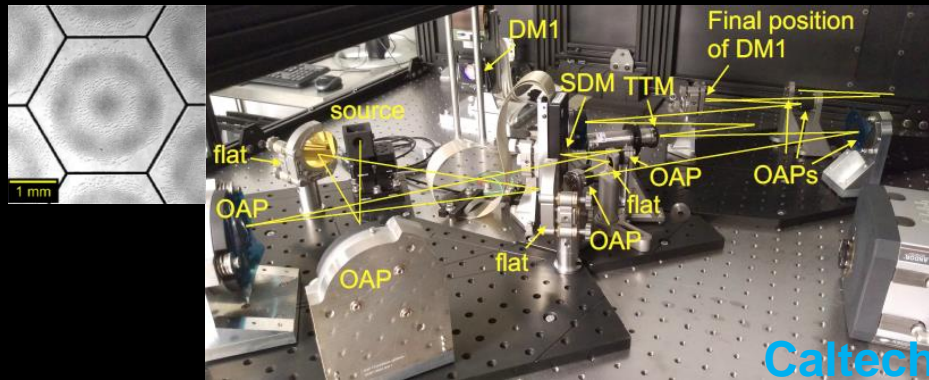
Entrance pupil Pupil-plane apodizer



From Ruane et al JATIS (2018)

SCDA next steps

- Lab tests of masks underway



- Robustness metrics for wavefront errors are being developed and designs will be evaluated against them
- FALCO (joint DM / apodizer optimizer) code public release imminent
- Designs to be tested within same PROPER software framework
- Many results to be presented at Austin SPIE: joint SCDA paper planned for this fall

TECHNOLOGY

MISSIONS

SCIENCE

Angular Resolution: Interferometry

Angular Resolution and Collecting Area: Large Space Telescopes

Contrast Stability: Ultrastable Structures

Detection Sensitivity: Advanced Detectors

Starlight Suppression: Starshades

Starlight Suppression: Coronagraphs



Hubble



Spitzer



Kepler



TESS



JWST



WFIRST



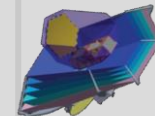
Starshade
Rendezvous



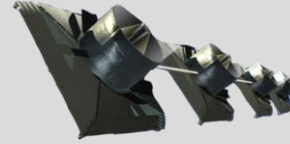
LUVOIR



HabEx



OST



Exo-Earth
Interferometer

TODAY

2020s

2025s

2030s

2035 and beyond

Exoplanetary
Atmospheres
Hot Jupiters

Exoplanet
Abundance

Nearest Transiting
Planets

Atmospheric
Chemistry

Direct Imaging
Exozodiacal Dust
Exoplanet Diversity

Habitable
Exo-Earth
Discovery

M-Dwarf Rocky Planet
Biosignatures
Cool Gas Giants

Exo-Earth
Biosignatures
Habitable
Exo-Earth
Abundance

Life
Verification

Possible Pending Decadal Survey

<https://exoplanets.nasa.gov/exep/technology/technology-overview/>



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Please visit the NASA ExEP website for more details:

<https://exoplanets.nasa.gov/exep/>